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Preliminary palaeomagnetic results from medium grade metacarbonates of the Lesser Himalaya

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ABSTRACT

First investigations of metacarbonates of the Lesser Himalaya close to the Main Central Thrust (MCT) demonstrate the suitability of medium grade metacarbonates for palaeomagnetic studies. Stable directions were obtained for a secondary thermoremanent magnetisation with unblocking spectra between 200-350°C, indicating pyrrhotite as the remanence carrier. The occurrence of pyrrhotite is evidenced in several sites by rockmagnetic investigations. Significant mean directions were found in sampling sites located south of the Manaslu massif (central Nepal) and also in the Alaknanda valley (Garhwal Himalaya, India). More stable remanences in the Alkananda valley can be related to single domain (SD) pyrrhotite whereas higher instabilities in central Nepal might be due to smaller grain sizes around the SD-superparamagnetic transition.

INTRODUCTION

Palaeomagnetic remanences from the Lesser Himalaya, when compared to the results from stable India and the units north of the Main Central Thrust (MCT), may provide information on systematic differences of Tertiary block rotations on both sides of the MCT. Quantitative evaluation of inclinations should allow to test and further quantify the model of the MCT Ramping (Appel et al., 1991; Rochette et al., 1994). Declinations may be useful to detect a possible propagation of the oroclinal bending to the south of the MCT (Klootwijk et al., 1985). Such rotation pattern would enable a more direct constraint for rotational underthrusting model (Klootwijk et al., 1985; Appel et al., 1991, 1995).

However, magnetic overprints due to widespread metamorphism limit the application of palaeomagnetism to a few successful studies of low grade metamorphic or sedimentary rocks in the southern part of the Lesser Himalaya (Klootwijk et al., 1982; Gautam 1990, 1994). Rochette (1987) reported that secondary pyrrhotite can be formed in carbonates during low grade metamorphism. Well-defined palaeodirections of thermoremanences (TRM) carried by such pyrrhotite were obtained from low grade metamorphic carbonates of the Tethyan Himalaya north of the MCT (Appel et al., 1991, 1995). This pyrrhotite component has been related to remanence acquisition during exhumation and cooling. Consistent directions indicate that remanence acquisition occurred below the transition of ductile to brittle deformation. Therfore, gelogical setting can significantly represent tectonic movements of relatively large scale. The Lesser Himalayan units close to the MCT are key zones for understanding block rotations along this prominent tectonic line. However, only medium grade metamorphic rocks are existing here. In this study we present results from metacarbonates of this zone to investigate their potential for palaeomagnetic interpretations. Major attention is directed to pyrrhotite, which acquires a TRM in the brittle deformation stage below about 300°C and may thus record stable remanences like in the Tethyan Himalaya.

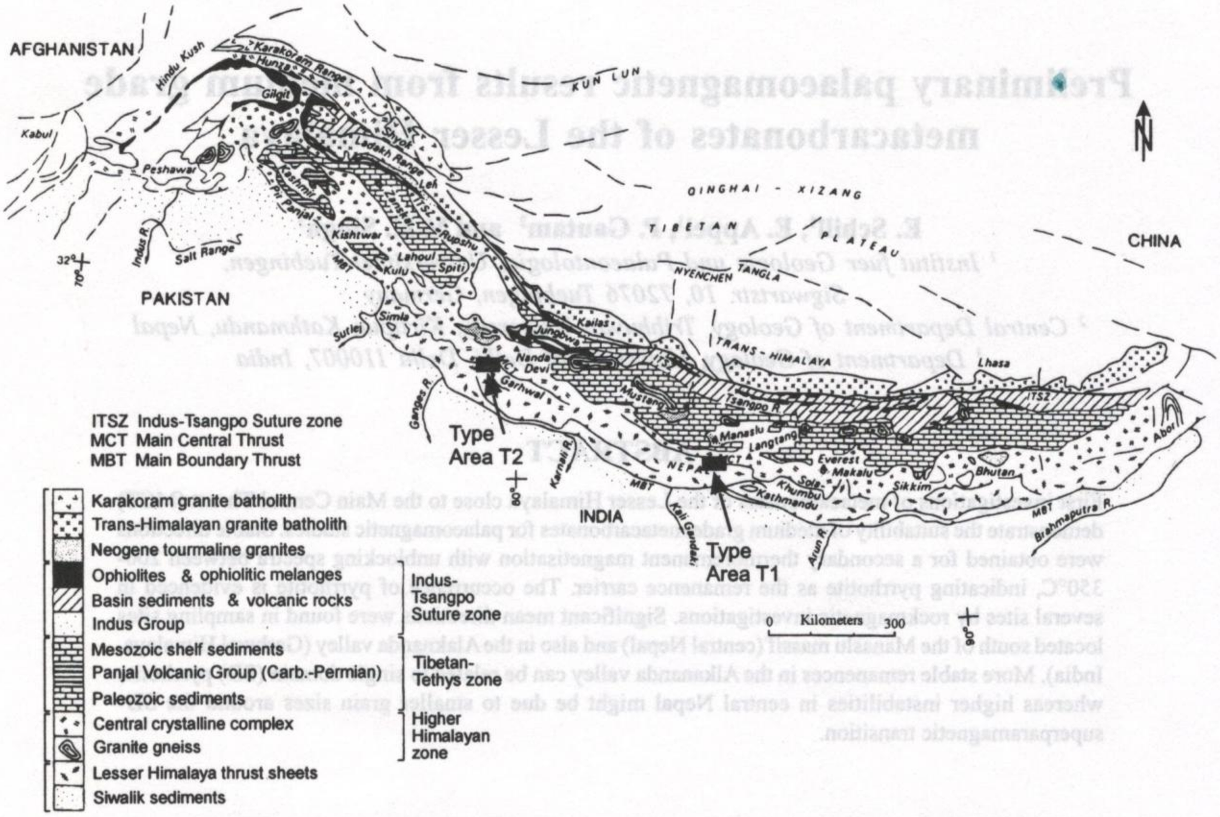


Fig. 1: Schematic map of the Himalayas with the main structural and stratigraphic units (after Searle et al., 1987). Full rectangles indicate the working areas T1 and T2.

PALAEOMAGNETIC SAMPLING

Sampling has been carried out in two areas of the Lesser Himalaya (Fig. 1): the Burhi Gandaki, Darondi, and Marsyandi valleys (type area T1, central Nepal) and the Alaknanda valley (type area T2, Garhwal Himalaya, India).

A portable rockdrill was used for sampling and orientation of cores was measured with a magnetic compass. Generally, about 10 cores, 2.5 cm in diameter, were taken at each site. In the type area T1, fourteen samples of the carbonates (limestones, dolomitic limestones, and dolomites) were taken from the Dhading Dolomite and seven samples from the Malekhu Limestone (Fig. 9). In the type area T2, 8 sites were taken from the carbonates of the Tejam and Jaunsar Groups (Deoban, Mandhali and Chandpur formations) (Fig. 8). The primary age of the metasedimentary rocks sampled is not clear. Since the expected TRM is of secondary origin, only the age of the last thermal event in the study areas has relevance for the palaeomagnetic results. Exact ages of such thermal/metamorphic event for these particular localities are also not available. However, a cooling age of 20 Ma is suggested in the surrounding areas (Rb/Sr age on biotite for the Kumaon Himalaya, Frank et al., 1977 and for gneisses from the Everest area, Ferrara et al., 1983) is believed to be valid also for these areas. Ages of about 20Ma seem to reflect the general trend of cooling in the central Himalaya (e.g. Godin et al., 1998).

GENERAL SAMPLE TREATMENT

The cores were cut into standard specimens (2.2 cm length). All magnetic measurements were carried out in the palaeomagnetic laboratory at the University of Tuebingen (Germany). Rock magnetic analyses were performed at least on one specimen per site. The temperature dependence of low-field susceptibility was studied using a CS-2 heating unit attached to a KLY-2 Kappabridge (Agico). For two pilot specimens the natural remanent magnetisation (NRM) was progressively demagnetised, one by heating in a MMTD1 (Magnetic Measurements) furnace, the other one by applying alternating fields (AF) using 2G600 automatic degaussing system (2G Enterprises). The remanence directions were measured with a SQUID magnetometer 755R of 2G Enterprises (noise level <0.01mA/m). The low-field magnetic susceptibility (k) was monitored after each step of heating to detect possible changes of magnetic mineralogy. The AF-demagnetised specimens were subjected to isothermal remanent magnetisation (IRM) acquisition by using a pulse magnetiser MMPM9 (Magnetic Measurements) at a maximum field of 2.75T and subsequent stepwise thermal demagnetisation of the saturation IRM (SIRM). The intensity of IRM was measured with a Minispin Spinner magnetometer (Molspin, noise level 0.2mA/m). Depending on the results of the pilot studies the remaining specimens were demagnetised in 10 to 20 suitable steps. Generally, one specimen from each core was measured. Orthogonal vector projections, principal component analyses, equal area projections and Fisherian statistics were used for determination of remanence components and for calculation of mean directions.

The pyrrhotite-based stable paleoremanence directions in the medium grade metacarbonate rock units, which exhibited diverse bedding attitudes in the field, were indeed well-defined in geographic coordinates indicating their secondary origin in general. Hence, the remanence directions are discussed without any kind of tectonic corrections. Tectonic folding and rotations of various scales, which form the matter of investigations, are believed to affect the remanences in various ways. Elaborate tests to determine such effects and also the relative contribution of syntectonic and post-tectonic remagnetisation to the total stable secondary paleoremanence will be possible in future when more data will be available.

MAGNETIC MINERALOGY

A relatively low saturation field (<300 mT) is typically found for the metacarbonates of type area T1, whereas a harder magnetic behaviour with a saturation field of about 500mT is observed for the type area T2 (Fig. 2a). Such difference in coercivity is also evident from AF demagnetisation of NRM. Thermal demagnetisation of NRM and SIRM show a dominance of maximum unblocking spectra around 250-360°C for both areas (Fig. 2; a and b). This temperature range includes the Curie temperature of pyrrhotite (325°C). The observed slightly higher unblocking temperatures in some specimens result from inaccuracy in recording the exact temperature distribution inside the furnace during heating. Ferrimagnetic pyrrhotite is clearly identified by a Hopkinson peak around 300°C (thermomagnetic runs of k, Fig. 2c) and an exactly defined Curie temperature of 325°C (saturation magnetisation, Fig. 2d). Heating leads to formation of new magnetite as indicated by the enhancement of k near 580°C and to partial destruction of pyrrhotite (less pronounced pyrrhotite peak during cooling). The identification of pyrrhotite by thermomagnetic measurements was successful for several sites, for others the ferrimagnetic concentration was to low. Optical microscopy could not directly detect pyrrhotite, which could be explained by submicroscopic grain sizes.

In some sites, dominance of magnetite (low coercivities of 15mT during AF demagnetisation, Fig. 3a) and haematite (unblocking temperatures of >650°C, Fig. 3b) could be identified. Saturation fields of <500mT observed in haematite containing metacarbonates are indicative of large multi-domain grains (Fig. 3c). This fact is also confirmed by optical microscopy. Thermomagnetic curves point to very small single domain magnetite (Hopkinson peak around 100°C) and reveal haematite by a Curie temperature of around 700°C (Fig. 3d).

A soft magnetic component is present in most specimens. However, the dominant ferrimagnetic mineral in the metacarbonates of both areas is clearly pyrrhotite. It occurs in ~65% of all samples (~60% in type area T1 and ~75% in type area T2). About 15% contain dominantly haematite (besides magnetite) and for 20% the magnetic mineralogy is not clear. No systematic variation in the distribution of pyrrhotite according to the grade of metamorphism or stratigraphic differences was observed. Also, there are no macroscopic indications

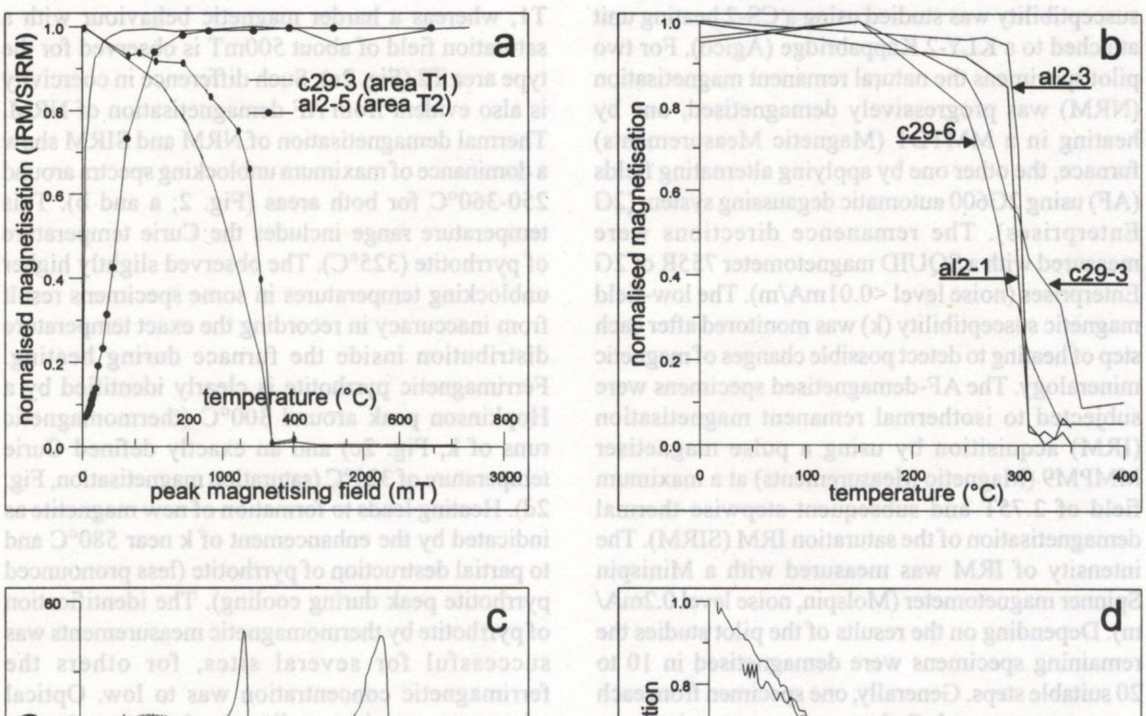


Fig. 2: Rockmagnetic results of representative specimens from the pyrrhotite-bearing, medium grade metacarbonates of the Lesser Himalaya. a) IRM acquisition and thermal demagnetisation of SIRM of specimens from site c29 (type area T1) and site al2 (type area T2), b) Thermal demagnetisation of NRM of specimens from sites c29 and al2, c) Low field susceptibility versus temperature plot for a specimen from site c29, d) Saturation magnetisation versus temperature plot for a specimen from site c29.

which could allow identification of sites containing pyrrhotite directly in the field.

REMANENCE ANALYSES

The sites with clear magnetic mineralogy (~80% of the total sites) were demagnetised thermally. Besides a present field direction carried by magnetite, a second remanence direction carried either by haematite (~20% of the demagnetised sites) or pyrrhotite (~80% of the demagnetised sites) could be separated. Since the TRM carried by pyrrhotite may have relevance for stable secondary palaeo-remanences, only this component is discussed in this paper.

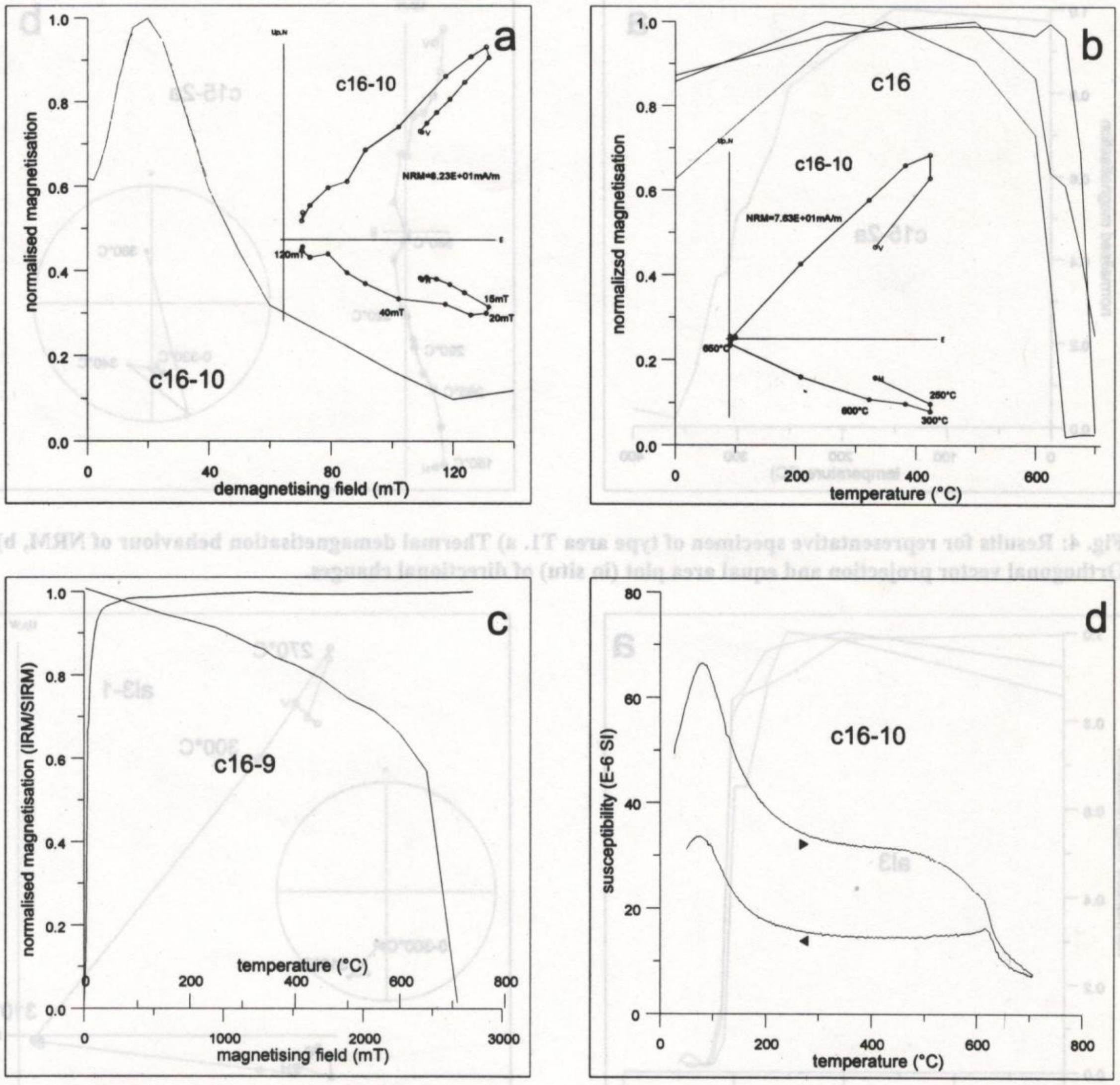


Fig. 3: Rockmagnetic results of representative specimens from haematite-bearing, medium grade metacarbonates of the Lesser Himalaya (site c16). a) Thermal demagnetisation behaviour and orthogonal vector projection (inset) of NRM, b) AF demagnetisation behaviour and orthogonal vector projection (inset) of NRM c) IRM acquisition curve and thermal demagnetisation behaviour of SIRM, d) Low field susceptibility versus temperature plot.

Thermal demagnetisation proved to be suitable for separating the pyrrhotite component. Generally, relatively broader unblocking temperature spectra were observed for the pyrrhotite component of type area T1 (sites c15, c24, c28, c29, c31, c34, c76-79, c82, Fig. 4) as opposed to type area T2 (site al2-5 and al 7-8) with more narrow unblocking range (Fig. 5). Grain size variations are likely to account for these differences.

Sites c76-79, and also many other specimens from both type areas, show the presence of two nearly antiparallel directions (Fig. 6a and b) demonstrated by a pronounced "kink" in the intensity curves during heating (Fig. 7). The unblocking spectra of 250-265°C and 280-290°C (both indicating pyrrhotite) in sites c76-79 are very narrow and the demagnetisation paths are only defined by two or three steps (Fig. 7a). In

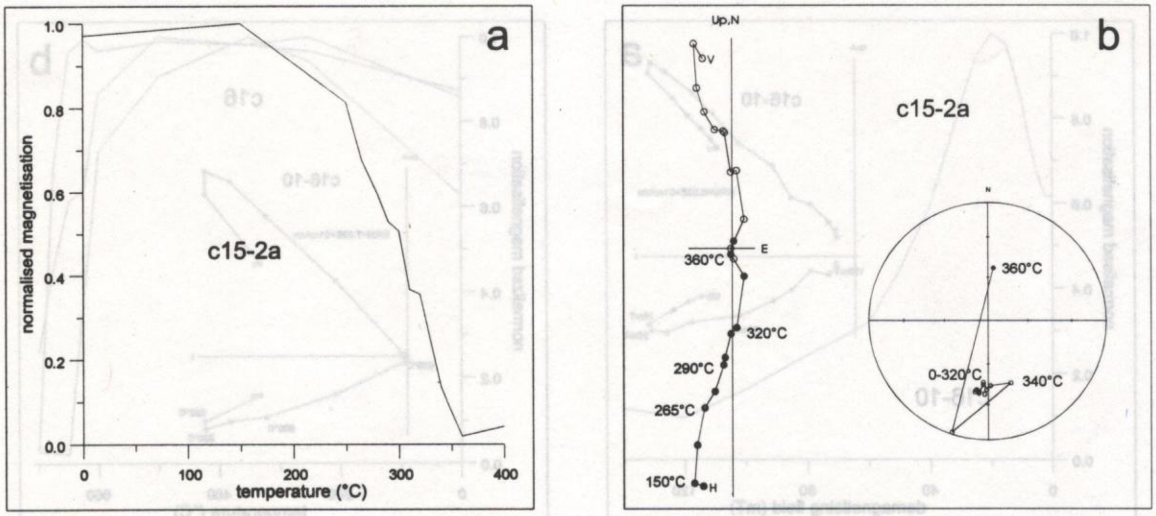


Fig. 4: Results for representative specimen of type area T1. a) Thermal demagnetisation behaviour of NRM, b) Orthogonal vector projection and equal area plot (in situ) of directional changes.

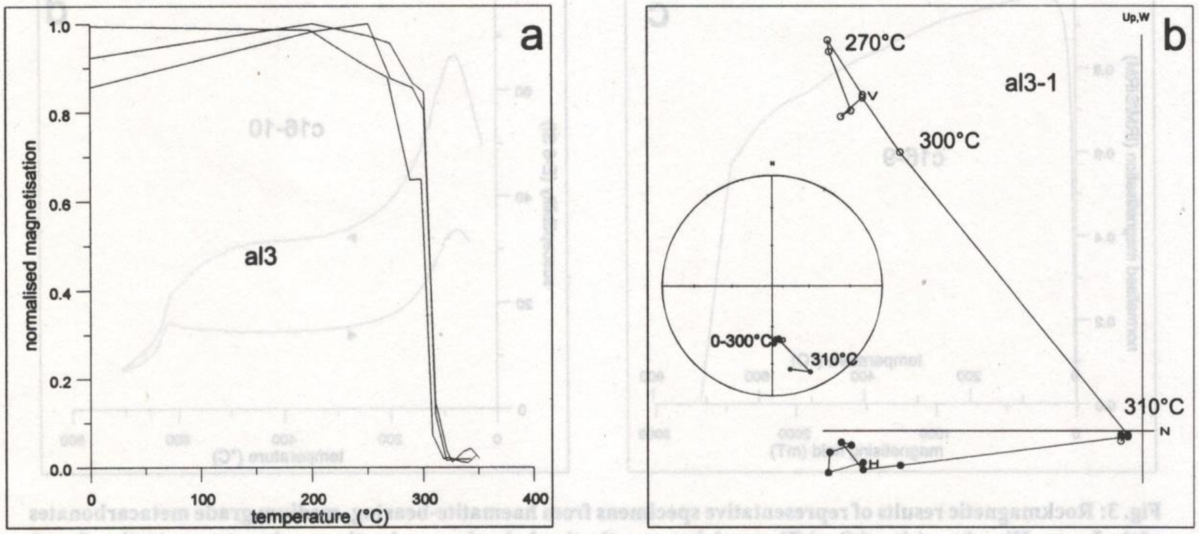


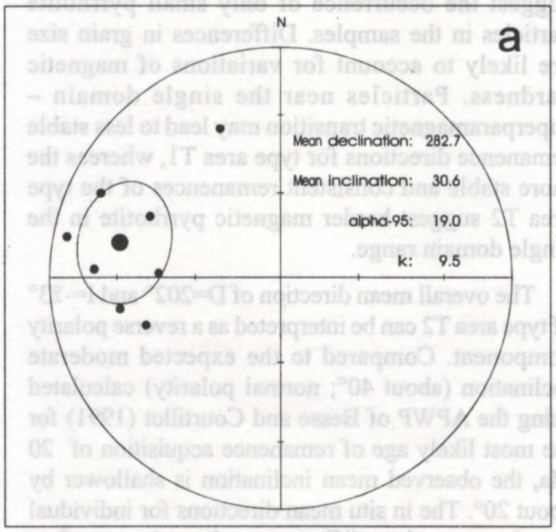
Fig. 5: Results for representative specimen of type area T2. a) Demagnetisation behaviour, b) Orthogonal vector projection and equal area plot (in situ) of directional changes.

some other specimens (e.g. site c31) the antiparallel components are clearly defined by several points (Fig. 7b). These sites are possibly recording a field reversal during cooling. This topic deserves further investigation.

The characteristic directions of individual specimens were determined between 250-290°C and the maximum unblocking temperature of pyrrhotite for both type areas. Calculation of site mean directions was done using a total of 86% of all specimens from the above mentioned pyrrhotite-containing sites. In rejected specimens, the content of pyrrhotite is too low or the NRM intensities are close to the noise level of the magnetometer. The resulting mean directions are listed in Table 1.

Table 1: Site mean directions (in situ) with statistical parameters. (1), (2), (3), denote different components found in the same site. Sites c and sites al followed by numbers represent type area T1 and T2, respectively.

Site Name	Unblocking temperature spectra (°C)	Declination (°)	Inclination (°)	Precision value	α95 (°)	Number of specimens
c15	265-360	190.6	-47.4	4.5	24.3	6
c24	310-340	77.6	18.9	9.1	14.6	7
c28	240-340	258.6	-6.4	4.6	31.7	7
c29	290-340	192.5	-28.1	41.8	8.1	6
c31	250-360	9	27.4	8.6	14.4	6
c34	280-310	329.2	-1.9	4.4	32.4	6
c76 (1)	250-265	83.5	22.3	12.5	77.8	2
c76 (2)	280-290	219.7	-16.3	3.8	45.3	5
c77 (1)	250-265	295.7	22.4	4.5	24.4	11
c77 (2)	280-290	84.9	-30.8	4.4	26.1	10
c78 (1)	250-265	236.6	-22.6	14.1	21.1	5
c79 (1)	250-265	282.7	39.6	9.5	19	8
c79 (2)	280-290	67.9	-28.6	6.8	23	8
c79 (3)	290-340	192.9	41.3	6	26.7	7
c82	300-360	178	-17.1	51.1	6.4	11
a12	270-300	206.8	4	26.2	15.7	5
a13	200-320	193.2	-35.1	51.9	7.2	9
a14	270-325	208.8	-22.2	29	9.1	10
a15	200-290	204	-17.8	21.3	10.1	11
a17	300-370	210	-24.7	10.3	31.8	4
a18	290-320	183	-42.3	39.2	12.8	6



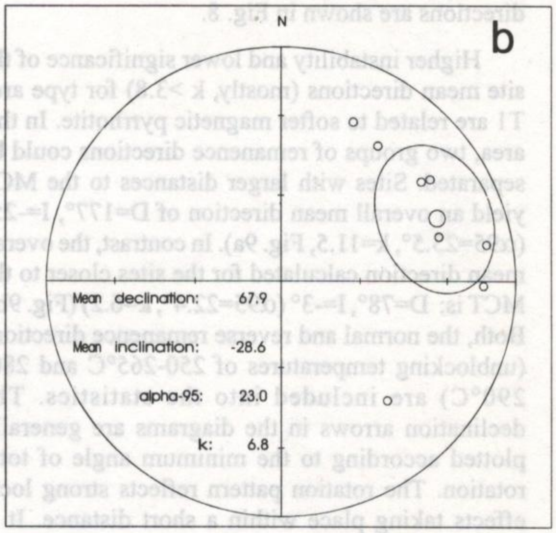


Fig. 6: Equal area plots of single specimen directions (small filled and open circles) from site c79 (type area T1) with mean directions (circles) and α95 cones. a) Unblocking spectrum 250-265°C, b) Unblocking spectrum 280-290°C. Filled and open symbols denote positive and negative inclinations respectively.

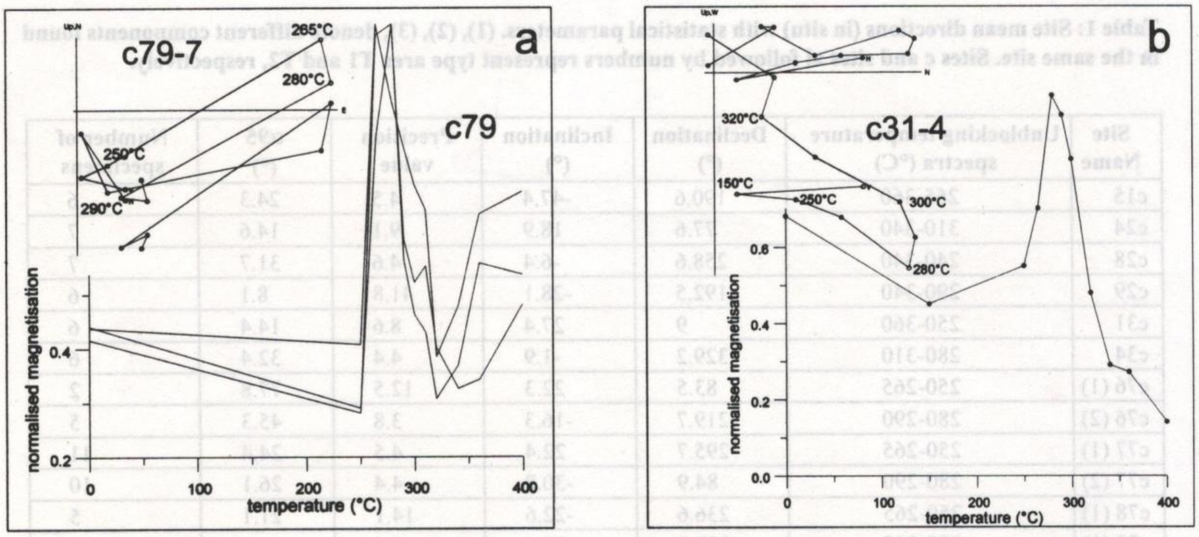


Fig. 7: Remanence intensity decay curves and orthogonal vector projections showing thermal demagnetisation behaviour of specimens possibly representing the earth's magnetic field reversal.

Evidence for the suitability of medium grade metacarbonates of the Lesser Himalaya for palaeomagnetic studies is provided by significant site mean directions (k>10) of type area T2. The mean direction of 6 sites (D=202°, I=-23°, k=19.5, α95=15.5°) is well defined. Reverse polarities are predominating and exclude a recent magnetic overprint. The declination values of the site mean directions are shown in Fig. 8.

Higher instability and lower significance of the site mean directions (mostly, k >3.8) for type area T1 are related to softer magnetic pyrrhotite. In this area, two groups of remanence directions could be separated. Sites with larger distances to the MCT yield an overall mean direction of D=177°, I=-25° (α95=23.5°, k=11.5, Fig. 9a). In contrast, the overall mean direction calculated for the sites closer to the MCT is: D=78°, I=-3° (α95=22.4°, k=6.2) (Fig. 9b). Both, the normal and reverse remanence directions (unblocking temperatures of 250-265°C and 280-290°C) are included into the statistics. The declination arrows in the diagrams are generally plotted according to the minimum angle of total rotation. The rotation pattern reflects strong local effects taking place within a short distance. It is noteworthy that inverting polarity of sites c77 and c79 (Fig. 9b) would produce a more consistent rotation pattern.

CONCLUSIONS

Our study demonstrates that medium grade metacarbonates from the Lesser Himalaya close to the MCT are in part suitable for palaeomagnetic studies. Evidence is provided for a secondary TRM with a major unblocking spectra between 200-360°C, indicating pyrrhotite. Microscopic observations suggest the occurrence of only small pyrrhotite particles in the samples. Differences in grain size are likely to account for variations of magnetic hardness. Particles near the single domain – superparamagnetic transition may lead to less stable remanence directions for type area T1, whereas the more stable and consistent remanences of the type area T2 suggest harder magnetic pyrrhotite in the single domain range.

The overall mean direction of D=202° and I=-23° of type area T2 can be interpreted as a reverse polarity component. Compared to the expected moderate inclination (about 40°; normal polarity) calculated using the APWP of Besse and Courtillot (1991) for the most likely age of remanence acquisition of 20 Ma, the observed mean inclination is shallower by about 20°. The in situ mean directions for individual sites, however, show differences and may in part reflect yet undetected variable tilting of individual sectors following the acquisition of the stable secondary

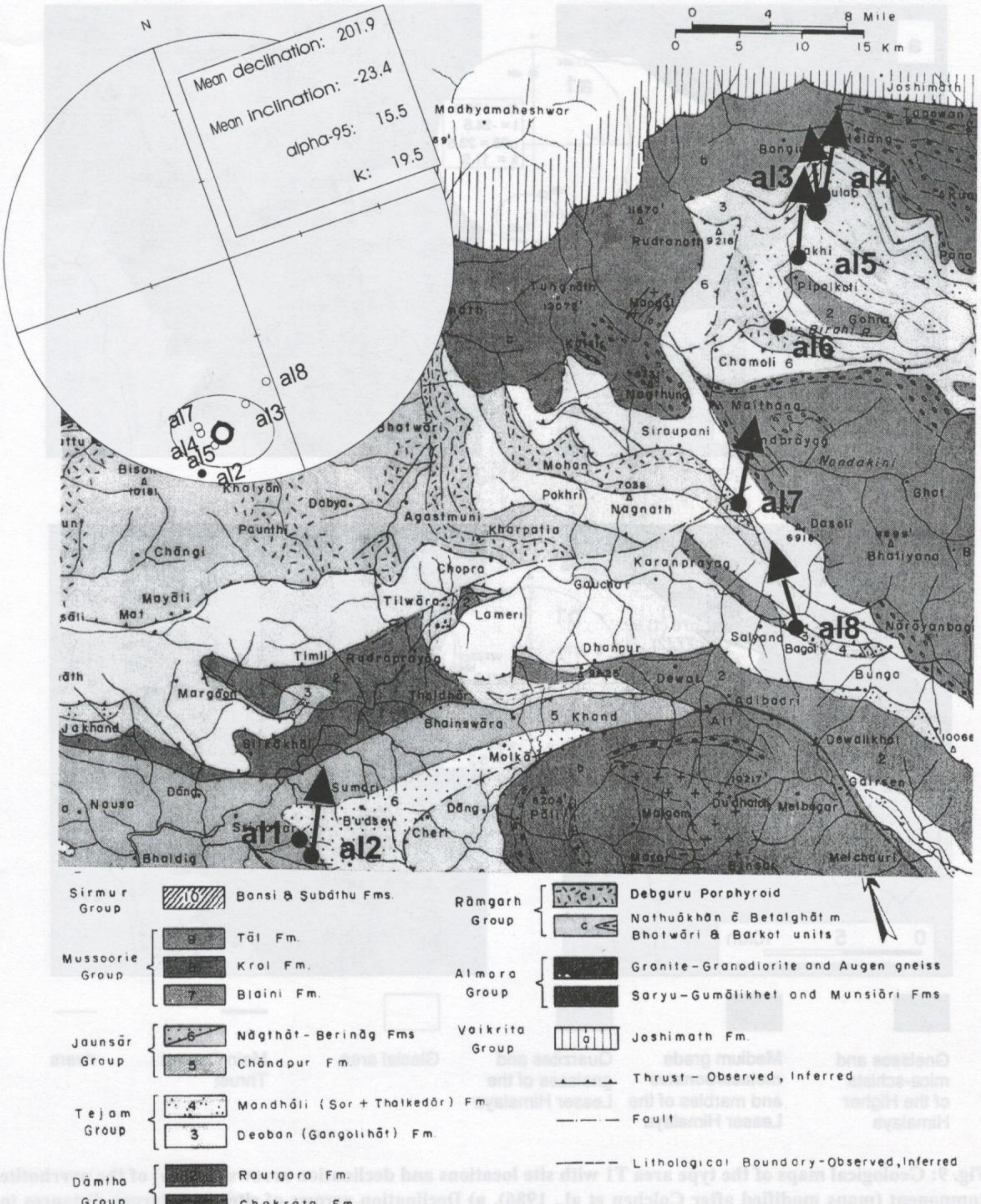


Fig. 8: Geological map (Valdiya, 1981) of the type area T2 with site locations, declination arrows (in situ) and equal area plot of site mean directions of the pyrrhotite component. The overall mean direction (large open circle) and α95-cone are shown. Filled and open symbols denote positive and negative inclinations respectively.

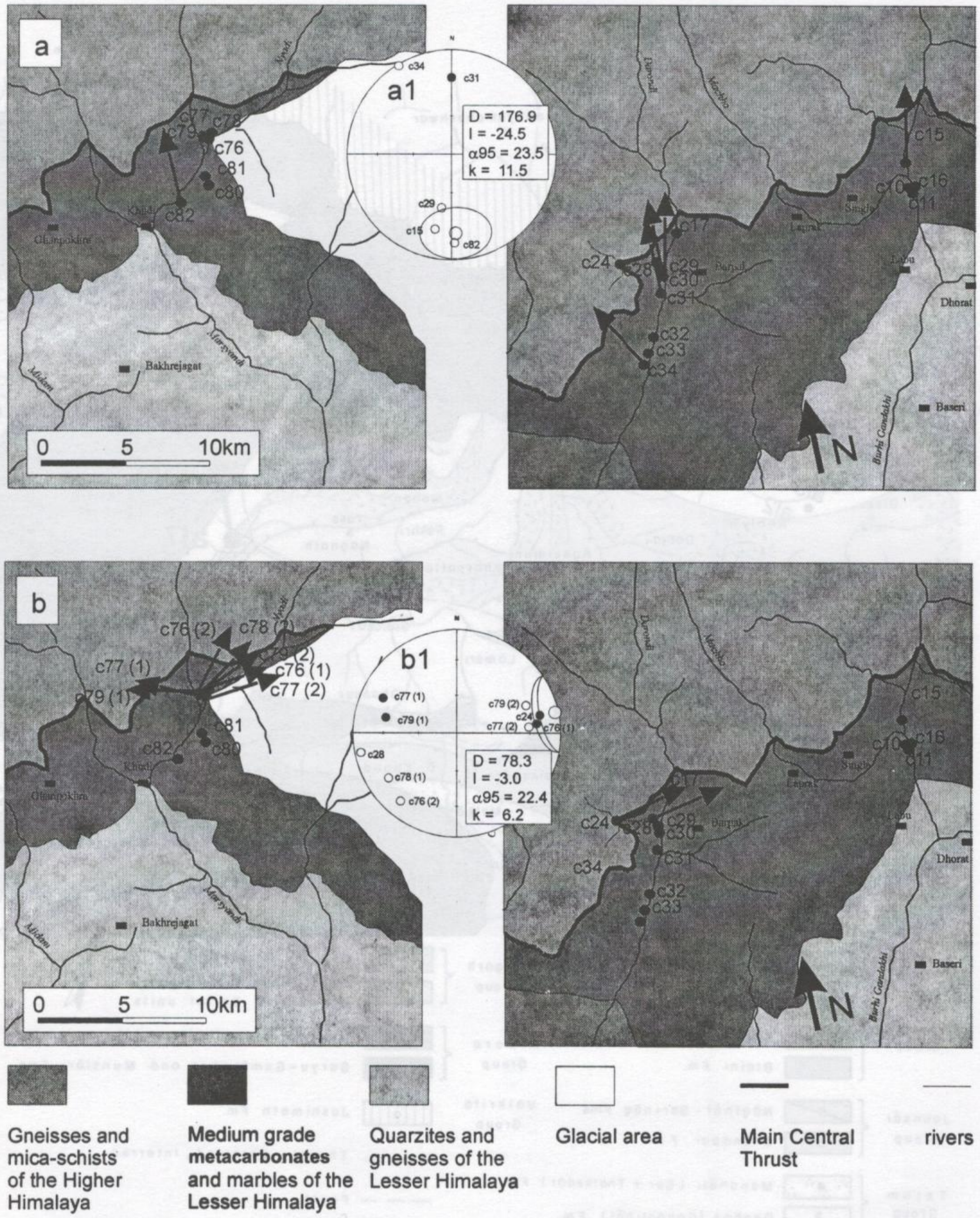


Fig. 9: Geological maps of the type area T1 with site locations and declination arrows (in situ) of the pyrrhotite component (maps modified after Colchen et al., 1986). a) Declination arrows of sites with larger distances to MCT, b) Declination arrows of remanence directions with unblocking spectra of 250-265°C (1) and 280-290°C (2) of sites closer to the MCT. For a1, and b1, equal area plots of site and overall mean directions (large open circles) and α95 cones are shown of sites located relatively far from the MCT. Filled and open symbols denote positive and negative inclinations respectively.

remanence. Such differences, when estimated more accurately, could be used to refine the model of 'MCT Ramping' (Appel et al., 1991). Further work is planned to provide a more precise quantitative evaluation and better tectonic interpretation.

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